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POLYURETHANE FOAMS FOR AIRCRAFT SHOCK MOUNTS III VIBRATION DAMPING BY POLYETHER FOAMS

BY JAMES V. DUFFY

RESEARCH AND TECHNOLOGY DEPARTMENT

JULY 1981

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NAVAL SURFACE WEAPONS CENTER

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The objective of this program was to develop flexible foam systems which would meet the specifications outlined in MIL-F-81334B(AS). The vibration damping and mechanical properties of a series of foams based on mixtures of poly(oxytetramethylene) glycol and poly(oxypropylene) polyol were determined. The effect of polyol ratio, foam density, surfactant type and unit loading on vibration output and transmissibility for these systems is reported.

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FOREWORD

The objective of this program was to develop flexible foam systems which would meet the specifications outlined in MIL-F-81334B (AS). This report deals with the vibration damping characteristics and mechanical properties of a series of foams based on mixtures of poly(oxytetramethylene)glycol and poly(oxypropylene)polyol. The effect of polyol ratio, foam density, surfactant type and unit loading on vibration output and transmissibility for these systems is reported.

This program was funded by the Naval Air Systems Command (AIR - 5163D2) under AIRTASK number A510-510C/001 - 4/9510 - 000 - 002 as part of a materials deterioration block program administered by the Naval Air Development Center.

Dr. Hubert Booth, formerly of this laboratory, is recognized for the concept which led to the development of these foams and for his contributions during the initial formulation and testing stages of the program. Dr. Henry Miller of the General Plastics Manufacturing Co. was responsible for the fabrication of the foam samples described in this report.

J. R. Dixon

J. R. DIXON
By direction

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INTRODUCTION

Many Navy aricraft are required to carry sensitive electronic equipment on board to accomplish their mission. It is necessary to protect this equipment from the shock and vibration which occurs during an aircraft's departure, flight and landing. For this purpose, the equipment is secured to mounts which contain polyurethane foam that isolates the equipment from the aircraft by absorbing operational shock and vibration forces.

In the past, polyester polyurethane foams were used because of their strength properties, greater resistance to fuels and other organic fluids and their excellent energy absorption characteristics. Some of these polyester-based foams, however, experienced hydrolytic degradation or reverison with resulting damage to the equipment being protected. Polyether-based foams, on the other hand, while generally not as mechanically strong as the polyester-based foams do have good resistance to moisture and can be formulated to have good vibration damping properties.

During the past several years, NSWC/WO has been involved in a program to develop a polyether polyurethane foam which will meet or exceed the criteria established for vibration damping foams by MIL-F-81334B (AS).[1,2] From the many foam formulations evaluated, a series based on a mixture of poly(oxytetramethylene) glycol and poly(oxypropylene) polyol gave the best overall results. Foam properties such as compressibility, rebound, tensile strength, elongation, hydraulic fluid and hydrolytic resistance, porosity and vibration damping were used in making this determination.

This series was then fabricated under contract by the General Plastics Manufacturing Co. using techniques that produced foams which had cell counts and cell sizes similar to other commercial foams. This report details the results of the vibration damping and mechanical properties tests which were conducted on these foams.

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[1] Booth, H. J. and Duffy, J. V., "Polyurethane Foams for Aircraft Shock Mounts, I Polyether Based Foams," NSWC/WOL TR 78-125

[2] Booth, H. J. and Duffy, J. V., "Polyurethane Foams for Aircraft Shock Mounts, II Polybutadiene Based Foams," NSWC/WOL TR 78-162

EXPERIMENTAL

A. Foam Fabrication

Foams were fabricated from Pluracol 718/Polymeg 2000 ratios which varied between 80/20, 60/40, 40/60, and 20/80 at two different densities (4 and 6 lbs/cu ft) using the standard B-3136 surfactant originally developed with this system. Six new surfactants were investigated for use with these foams: Union Carbide's L-520, L-540, and L-5740; Dow Corning's DC-190 and DC-196; and H. Goldschmidt's BF-2370. The L-540 and BF-2370 surfactants were selected for further evaluation as a result of preliminary screening tests with small cup samples (100-200 gms. polyol).

The formulations made by the contractor are listed separately in the appendix of this report and have been identified by a six digit number of which the first four digits refer to the polyol ratio and the last two digits designate the foam density. For example, 802006 would mean a polyol ratio of 80 parts of Pluracol 718 (PL-718) to 20 parts of Polymeg 2000(PM-2000) and the foam has a density of approximately 6 lbs/cu ft. In addition, the letter which followed the identification code designates the surfactant so that B was B-3136 and BF was BF-2370 and L was L-540. The foam components were added in the order given in the appendix and premixed before the addition of the isocyanate with a Conn disc mixer (3" diameter).

An isocyanate index of 105 was used for all of these foams. The mixing time, mixing speeds and cream times are also given in Appendix A. In order to make the foams stable and to open the cells properly, is was necessary to add N-ethyl morpholine (NEM) to all the 6 lbs/cu ft foams and the 802004B foam. NEM catalyzes the isocyanate-water reaction much more than the urethane reaction so that the blowing reaction is increased relative to gelation thereby opening the cells at the proper time yielding a stable foam. All of the foams were post-cured at 110°C for 25-30 minutes after the completion of the foam rise. All weighings were made on a Mettler PC-4400 balance and all the weights reported are given in grams.

B. Vibration Damping

Foam samples (5x5x1") were bonded to 1/4" aluminum plates (Figure 1) using EA-9309.2 (Hysol Division - Dexter Corporation) epoxy resin as an adhesive. The ratio of resin to curing agent was 100/22 parts by weight, and the resin system was fully cured at ambient temperature. After bonding, a load which measured 5" x 5" was secured to the top plate. The base of the foam test sample was then mounted on an electrodynamic vibrator (Ling Model 246, Figure 2) which was used to control and maintain the input vibration over the levels and frequency ranges specified by MIL-F-81334B (AS). The vibration response of the test sample was derived from a piezoelectric accelerometer (Endevco Model 2313E) attached at the center of the test weight as shown in Figure 3. The response and control accelerometers were fed into charge amplifiers (Kistler Model 504A) which were adjusted to produce an output voltage of 10 mv/g. The amplified output voltage from the control accelerometer was then fed into an electronic servo (Unholtz-Dickie Model SP-7) which was used to drive a Ling 40 Kw power amplifier. The power amplifier was used to drive the vibrator to the required input levels. The amplified output of the response accelerometer was fed into an x-y plotter for comparison of the test samples' vibration characteristics with that of the response standard.

C. Density Measurement

Density measurements were made according to ASTM D1564-71 on specimens prepared for vibration damping (5x5x1") or mechanical properties' measurements (5x5x0.5"). The results are reported in Table 1.

D. Tensile Strength/Elongation

Tensile strength and elongation measurements were made in accordance with ASTM D1564-71 (Table 1 and Figs 19-21).

DISCUSSION OF RESULTS

A. Vibration Damping

The MIL-F-81334B (AS) specification for input vibration is shown in Figure 4 in which input acceleration (g) is plotted against frequency (Hz). The output acceleration and transmissibility envelopes which are plotted on the same graph define the limits of acceptable response from the foam under the conditions of the test.

An interim polyester foam presently being used on aircraft shock mounts is Bernel 866000 which though it has excellent vibration damping properties (Figs 5 and 6) is susceptible to hydrolytic degradation. The Bernel foam (5 lbs/cu ft) shows only minor excursions outside the output and transmissibility envelopes at 26 Hz and between 90-135 Hz.

The vibration output for NSWC foams 208004B to 802004B are shown in Figure 7 while the transmissibility curves are compared in Figure 8. The results show excellent damping properties for the 406004B, 604004B and 802004B foams with some excursions for the 208004B outside of the envelope. This same series of foams in the 6 lb/cu ft density (208006B to 802006B) do not damp as well as their 4 lb/cu ft counterparts (Fig 9 and 10). The resonance frequency for these foams falls between 34-39 Hz at which point the output response is too high and continues to be so out to about 200 Hz. The exception to this case was the response of the 802006B foam which had good damping and showed only a slightly high vibration output in the 100 Hz region.

The damping results for foams prepared from the two new surfactants L-540 and BF-2370 are shown in Figures 11-14. There was no apparent effect on vibration damping properties due to changes in the type of surfactant used at this particular foam density. The single exception to this generalization was the 802006B foam which outperformed both the 802006BF and 802006L foams.

All of the above tests were made with a dead load of 7.5 lbs (0.3 psi.) on the foam samples. Additional tests were made at 12.5 lbs (0.5 psi.) and 17.5 lbs (0.7 psi.) using the two best foam formulations 802004B and 802006B. For the 802004B foams (Figs 15 and 16), the resonant vibration at 28 Hz is lowered and the total response is reduced as the load/unit area increased. Some slight increases in response are seen at the lowest frequencies. In the case of the 802006 foams (Fig 17 and 18), the same type of leveling of the resonant peak is experienced with slight increases in response at the lower and upper frequency ranges.

B. Mechanical Properties

The intent of this report was to study the effect of polyol composition, foam density and surfactant on the vibration damping characteristics. Since vibration absorption is the single most important foam property, it was given the greatest emphasis and only a limited amount of mechanical properties data was collected. The tensile strength, elongation and modulus values for both the 4 and 6 lb/cu ft foams which employed B-3136 surfactant are reported in Table 1. In addition, the properties of the 6 lb/cu ft foams which used B-2370 and L-540 are also shown. The initial tensile strength of the 208004B and 208006B foams were 47.6 and 44.6 psi. respectively (Figs 19 and 20) which is excellent, but the strength falls off rapidly as the PM-2000 content of the foams decreased. At the 406004B and 406006B compositions, the tensile strength was below the military requirement of 30 and 25 psi. for these respective densities. The military requirement for elongation was only met by the 208004B and 208006B foams. It should be noted that the strength requirements in MIL-F-4133B (AS) were written for an open cell polyester foam which nominally have better tensile/elongation properties than do the polyether foams. Young's modulus of these foams was also determined from the stress-strain curves (Fig 21). It is interesting to note that the foams with moduli below 14 psi. have the best vibration damping properties. This relationship held for the 802006B, 406004B, 604004B and 802004B systems.

CONCLUSIONS

1. Foams have been fabricated from NSWC formulations in both 4 and 6 lb/cu ft densities which pass MIL-F-81334B (AS) specifications for vibration damping. The best foams in the series were 802006B, 406004B, 604004B and 802004B.

2. The vibration damping properties of the 6 lb/cu ft foams were not effected by changes in surfactants.

3. As anticipated, only the formulations which had high PM-2000 contents met the strength requirements of the MIL-F-4133B (AS).

RECOMMENDATIONS

1. Investigate changes in the existing polyol composition which could lead to improvements in the system's mechanical properties without effecting the vibration damping characteristics.

2. Submit the best foams to extensive testing as outlined in MIL-F-81334B (AS).

3. Evaluate the best foams in the field aboard selected Navy aircraft.

TABLE 1 MECHANICAL PROPERTIES OF NSWC FOAMS

Foam Formulations	Tensile Strength (psi)	Elongation (%)	Young's Modulus (psi)	Density (lbs/cu ft)
208004B	47.6	512	15.1	4.1
406004B	17.8	198	13.3	3.9
604004B	17.8	208	12.3	3.9
802004B	10.9	130	11.7	4.0
208006B	44.6	403	18.5	6.1
406006B	21.8	259	17.3	6.1
604006B	12.4	104	15.6	6.0
802006B	9.5	81	14.1	6.2
208006BF	52.7	454	18.3	6.2
406006BF	23.8	201	18.5	6.6
604006BF	13.7	105	17.8	6.6
802006BF	10.0	78	15.5	6.3
208006L	46.5	417	20.0	6.0
406006L	20.8	190	17.2	6.3
604006L	13.8	99	18.8	6.5
802006L	10	80	15.7	6.2

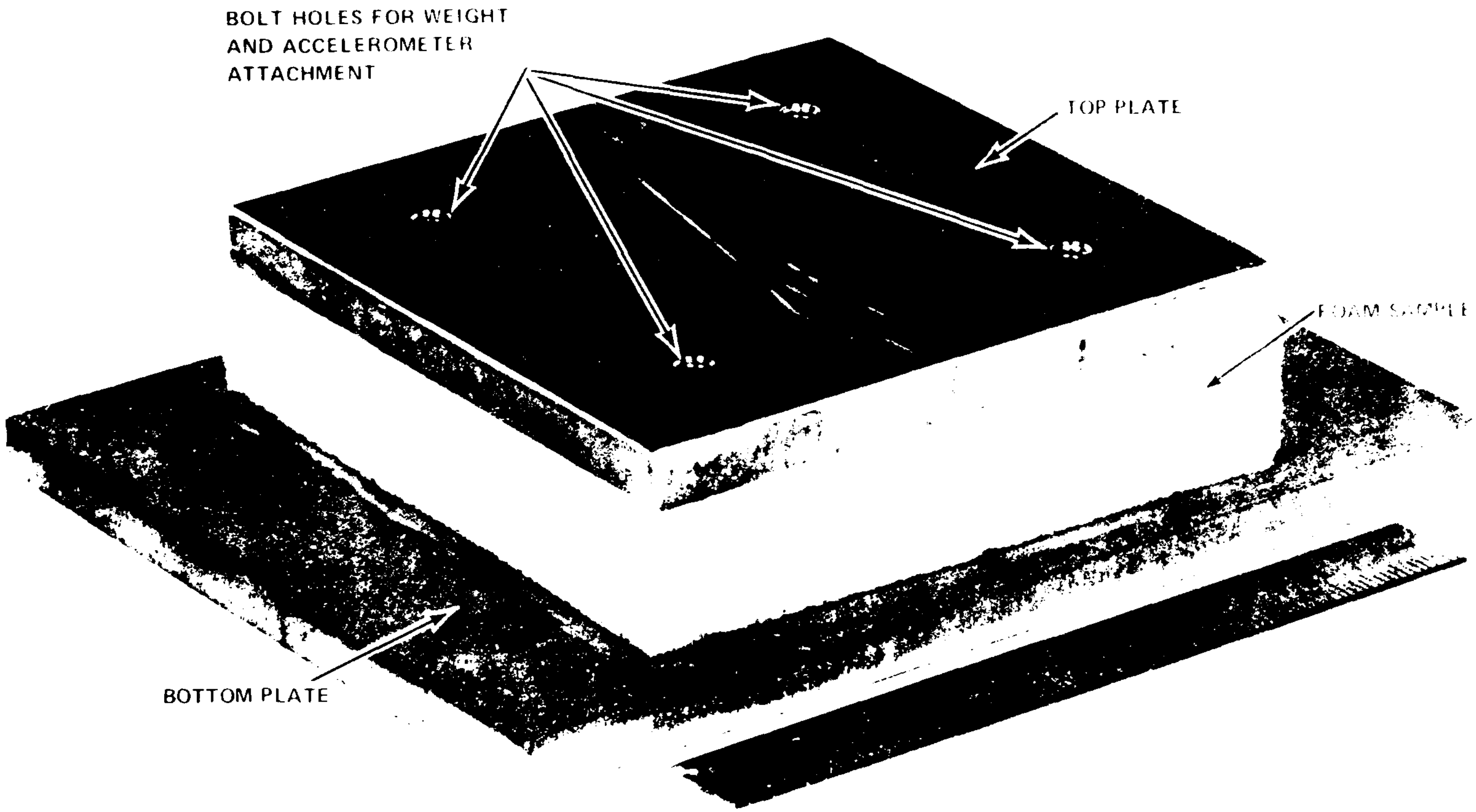

FIGURE 1 FOAM VIBRATION SAMPLES

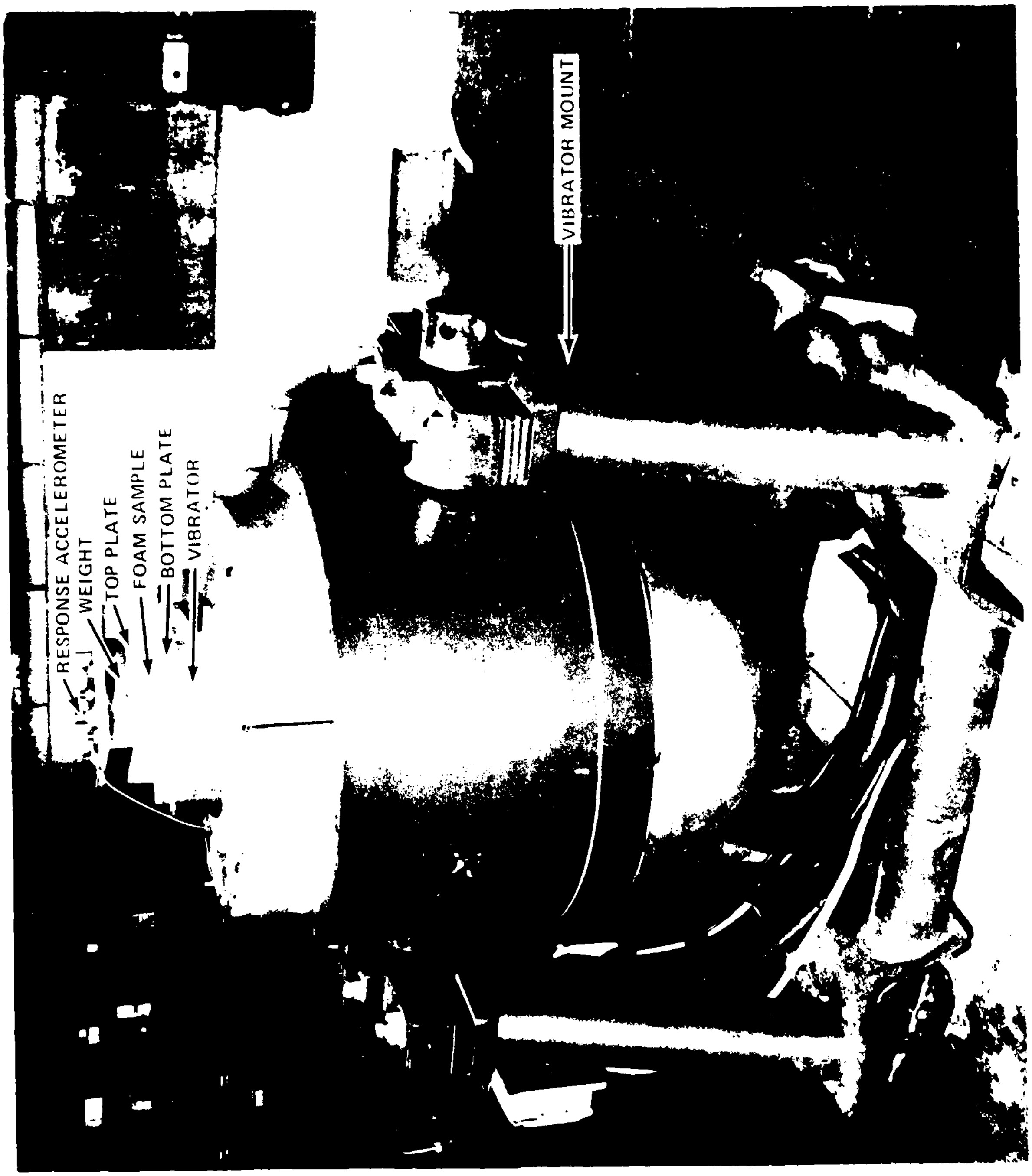

FIGURE 2 THE ELECTRODYNAMIC VIBRATOR

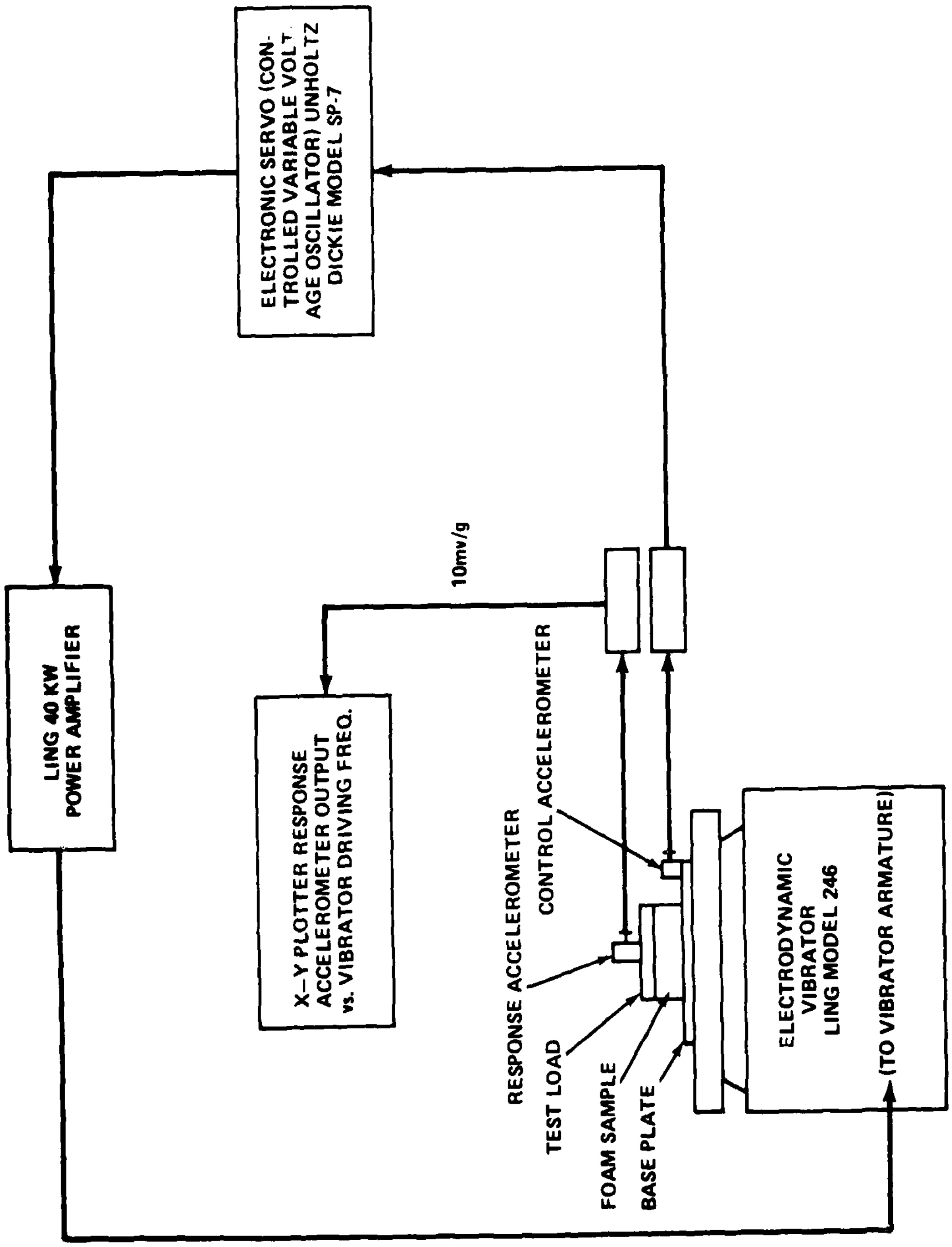

FIGURE 3 SCHEMATIC OF VIBRATOR EQUIPMENT

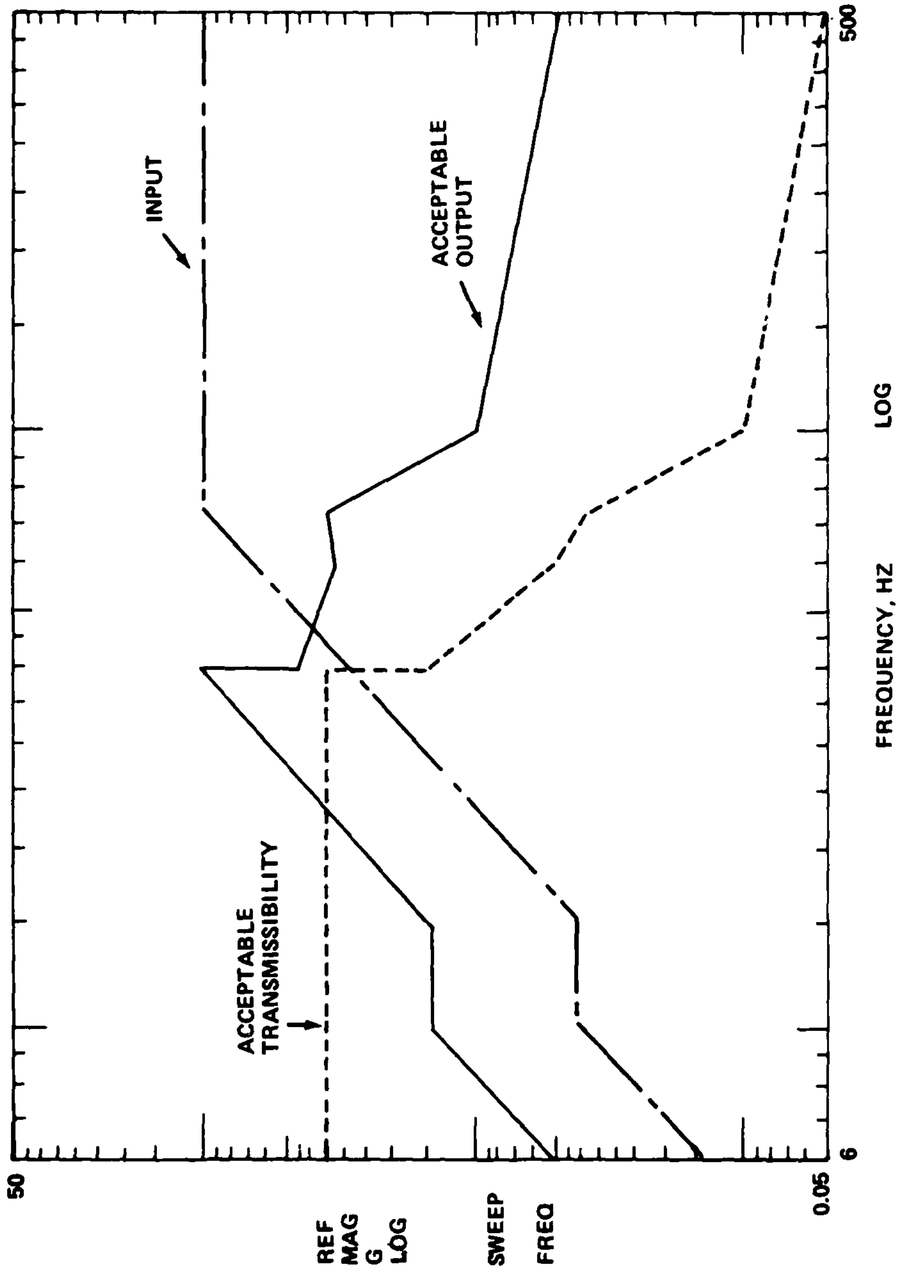

FIGURE 4 MIL–F–81334B (AS) – VIBRATION DAMPING SPECIFICATIONS FOR POLYURETHANE FOAM

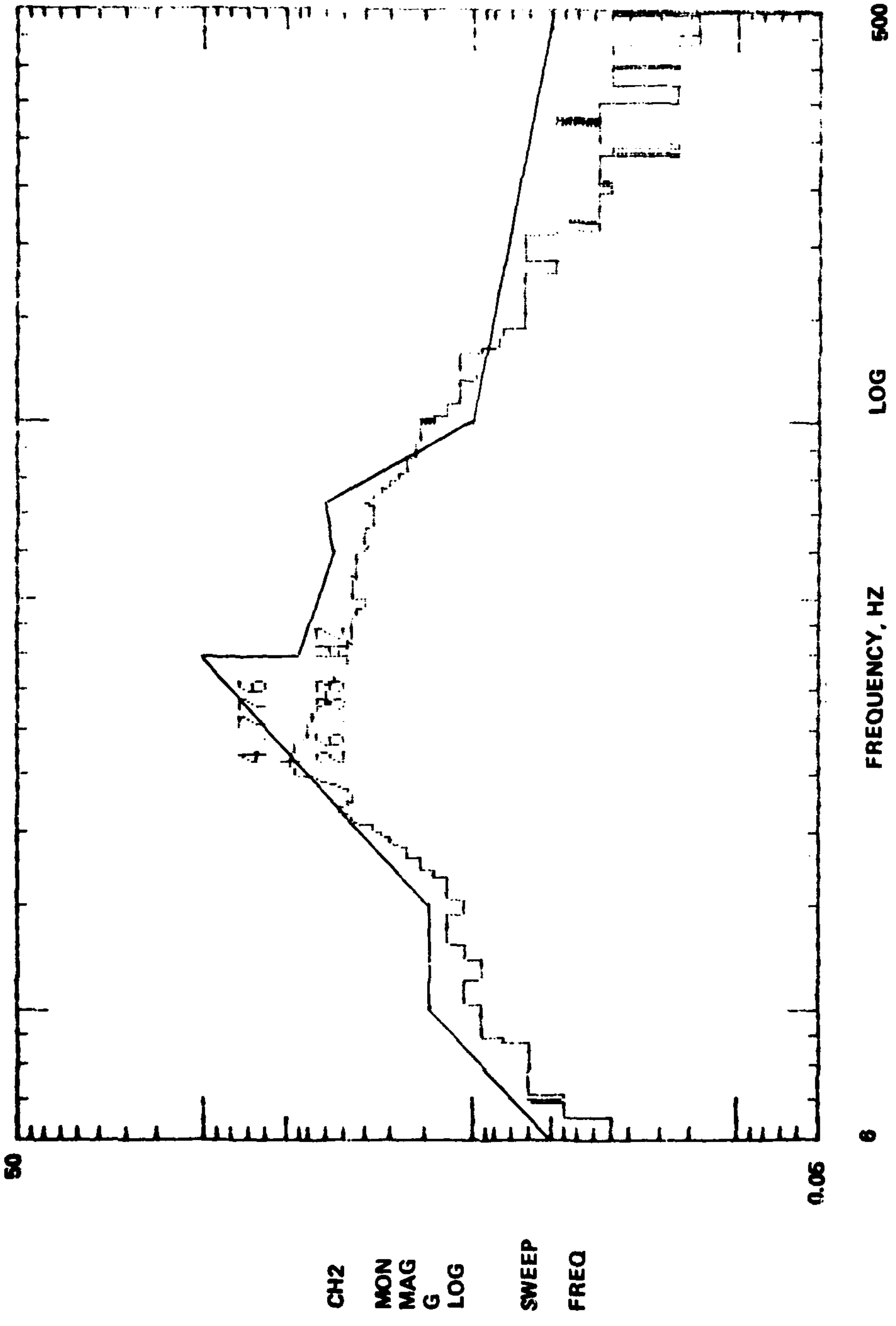

FIGURE 5 VIBRATION OUTPUT BERNEL 866000

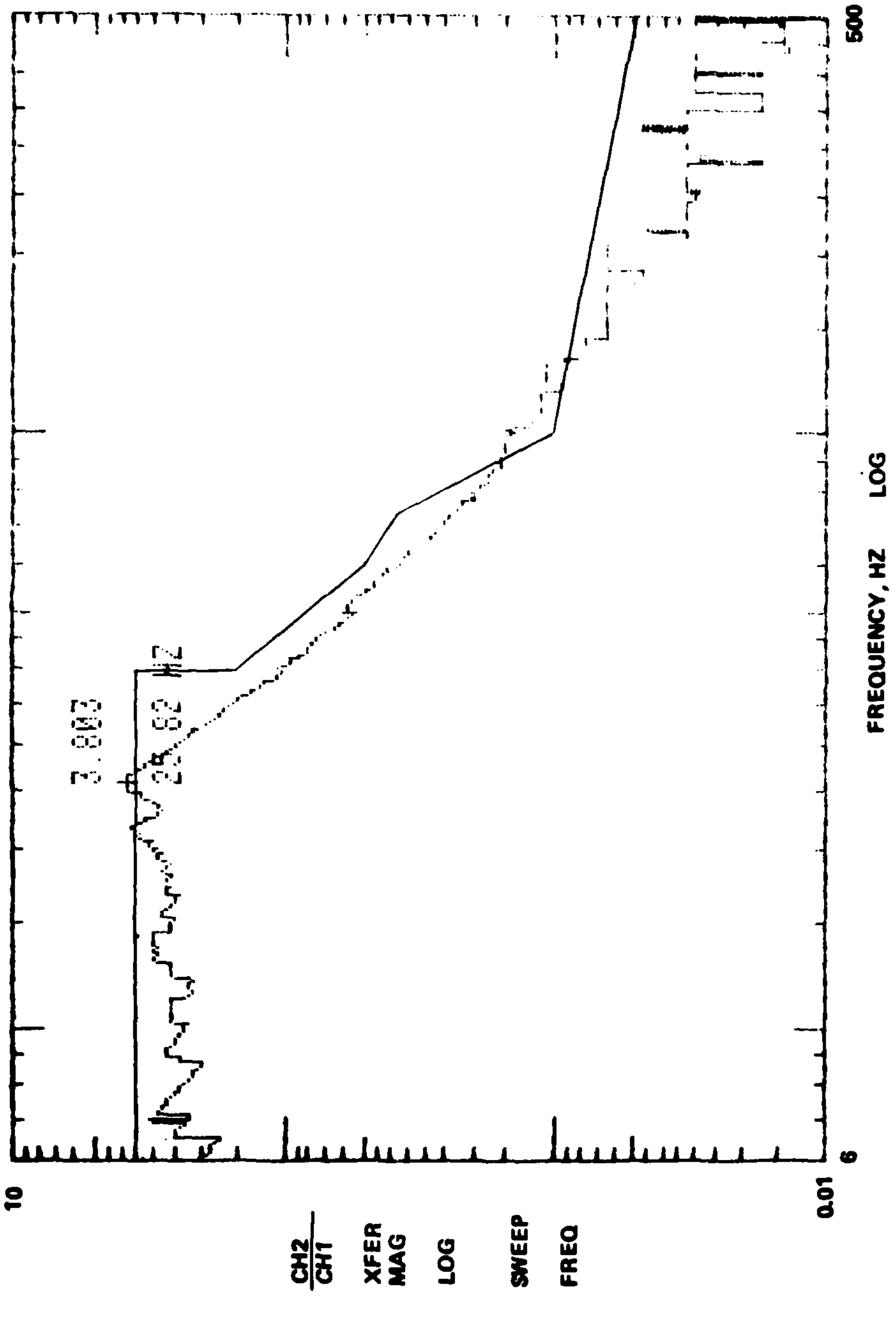

FIGURE 6 VIBRATION TRANSMISSIBILITY – BERNEL 866000

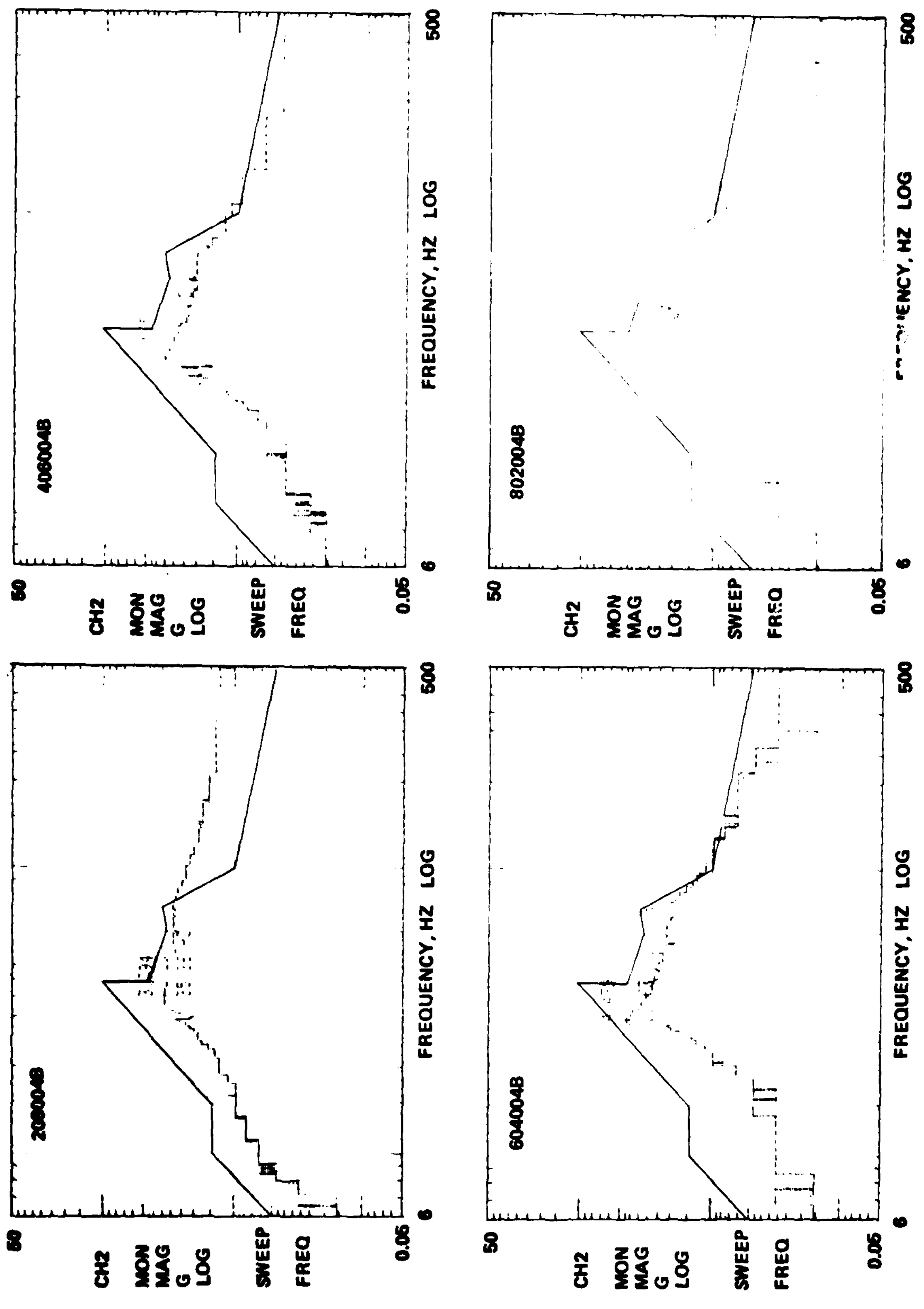

FIGURE 7 VIBRATION OUTPUT FOR NSWC FOAMS 206004B TO 802004B

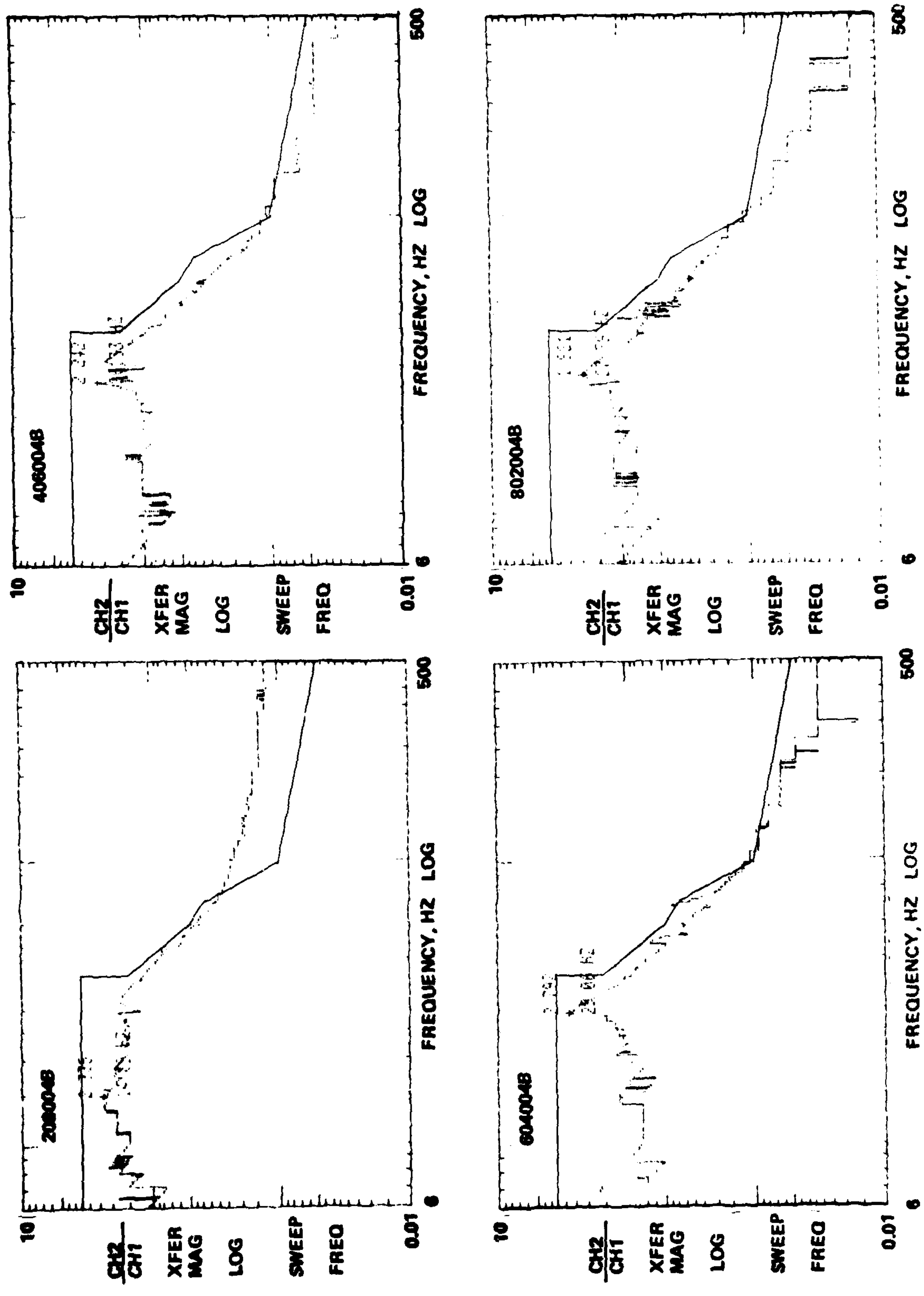

FIGURE 8 VIBRATION TRANSMISSIBILITY FOR NSWC FOAMS 208004B TO 802004B

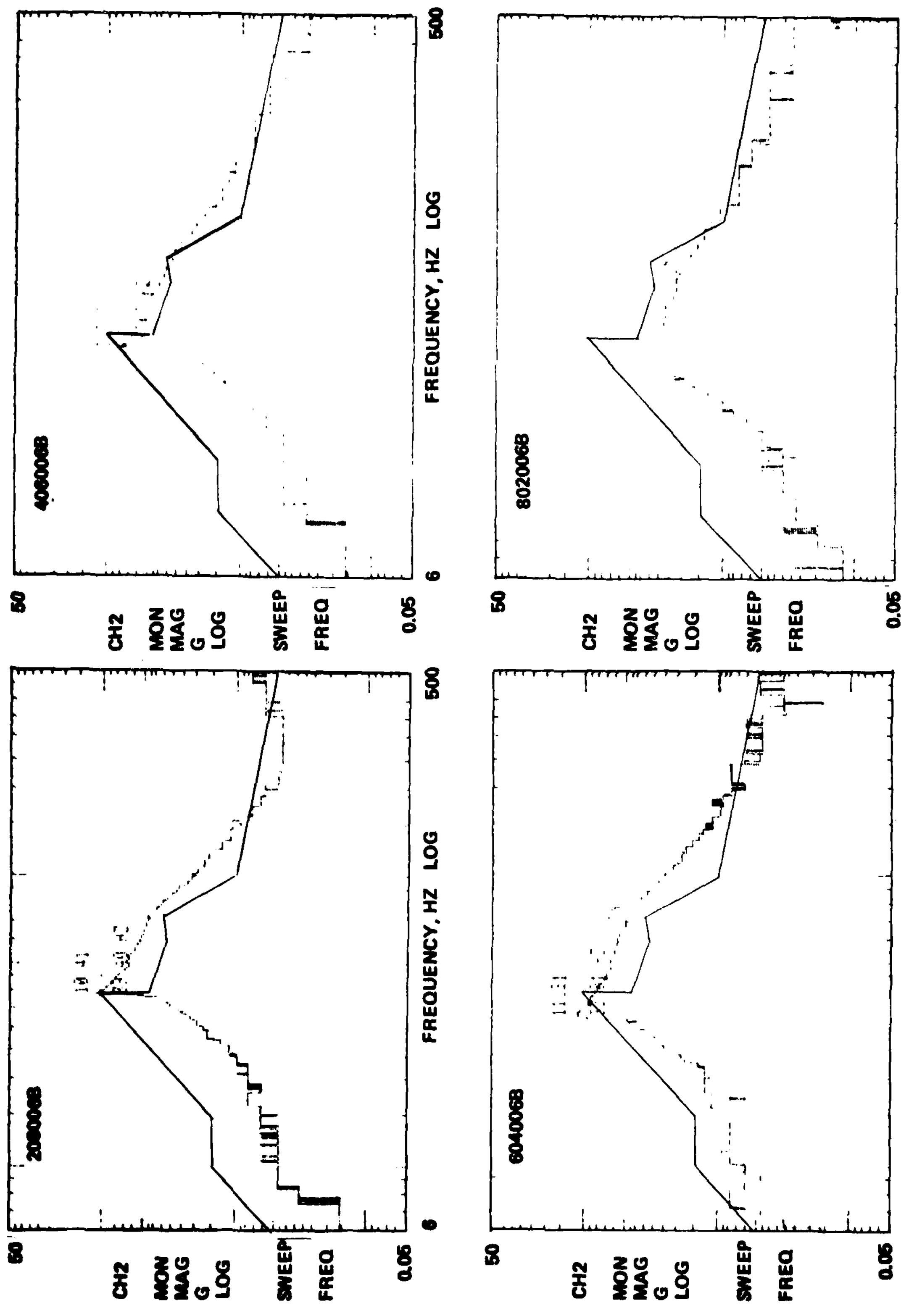

FIGURE 9 VIBRATION OUTPUT FOR NSWC FOAMS 2080068 TO 8020068

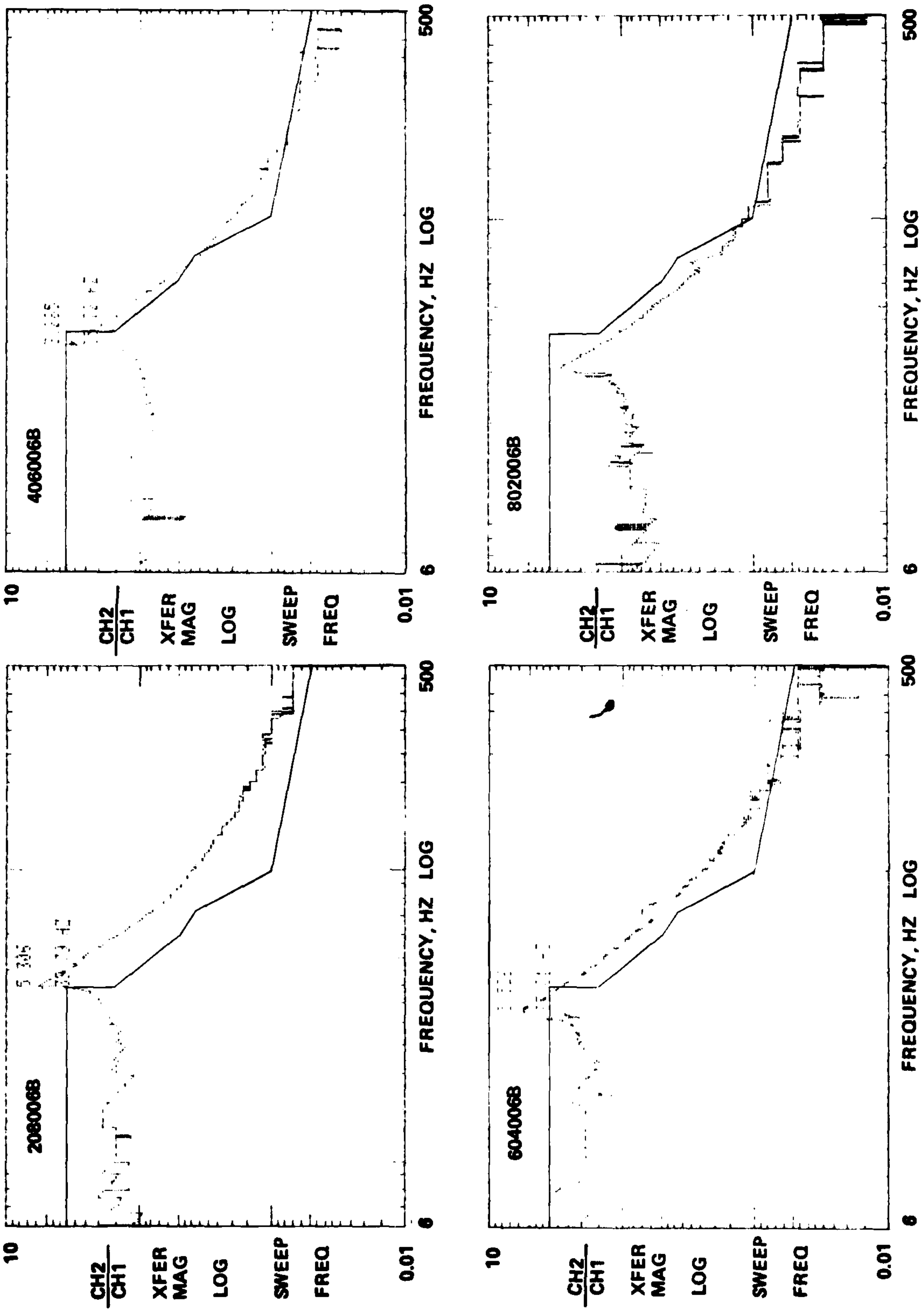

FIGURE 10 VIBRATION TRANSMISSIBILITY FOR NSWC FOAMS 208006B TO 802006B

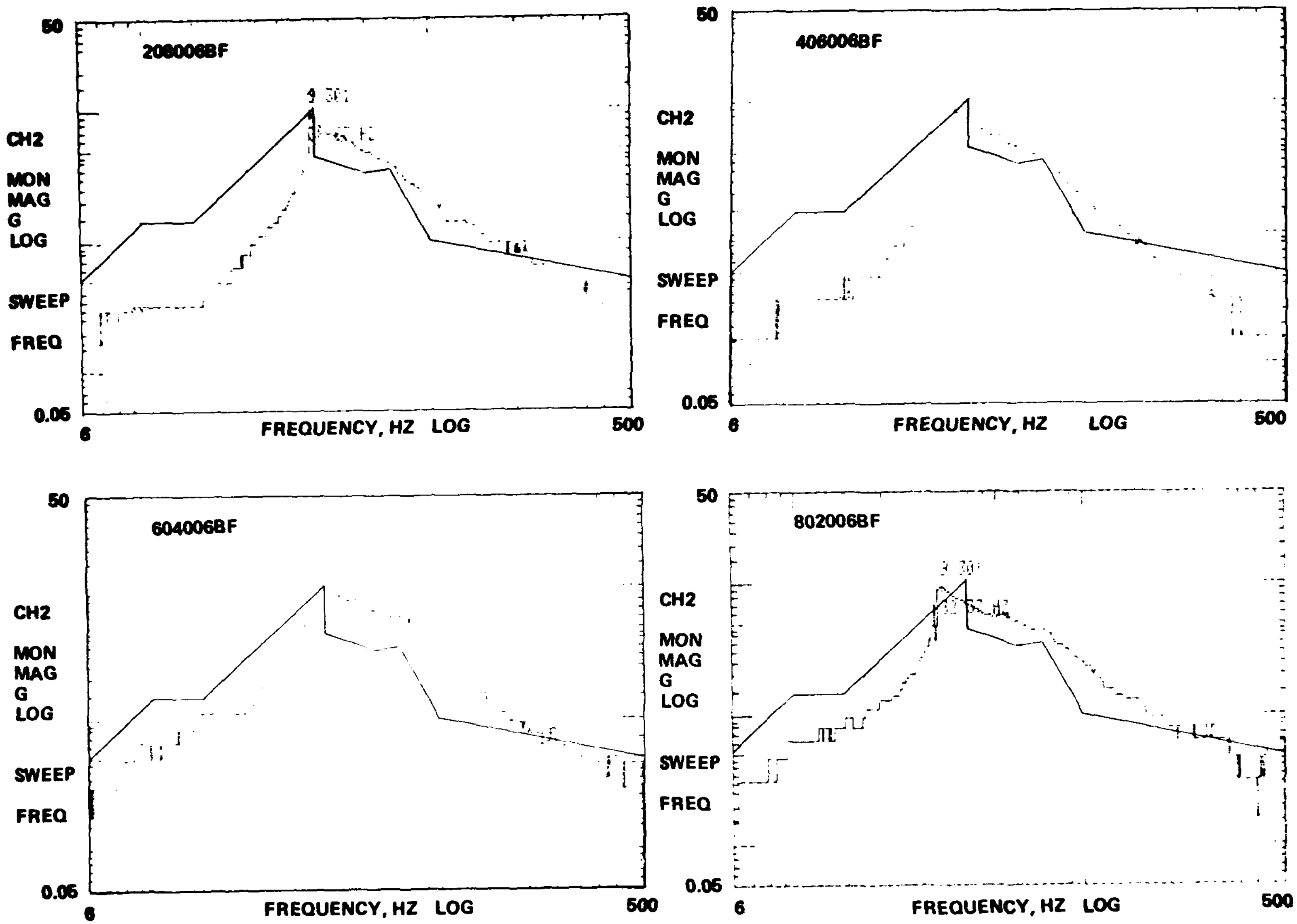

FIGURE 11 VIBRATION OUTPUT FOR NSWC FOAMS 208006BF TO 802006BF

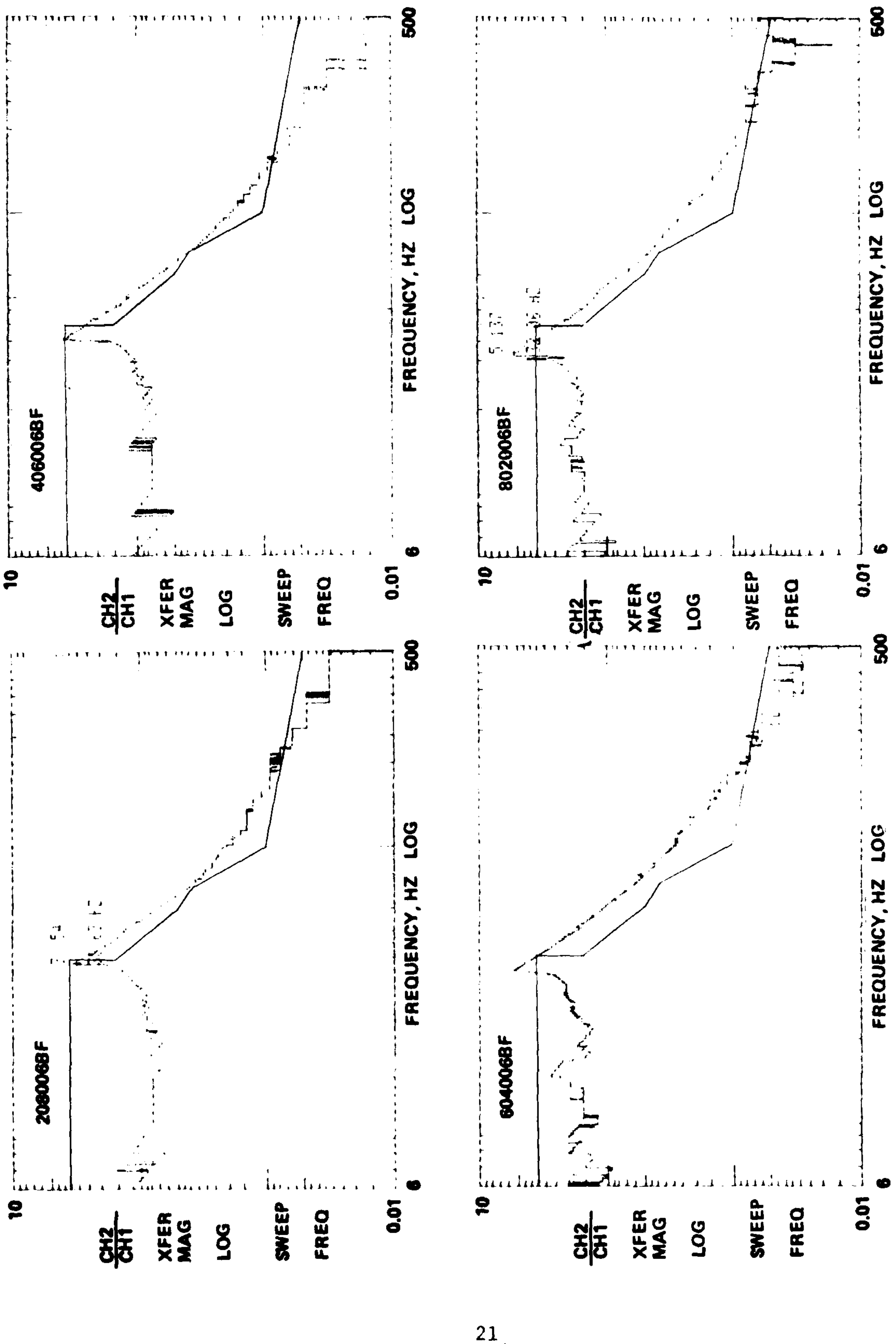

FIGURE 12 VIBRATION TRANSMISSIBILITY FOR NSWC FOAMS 208006BF TO 802006BF

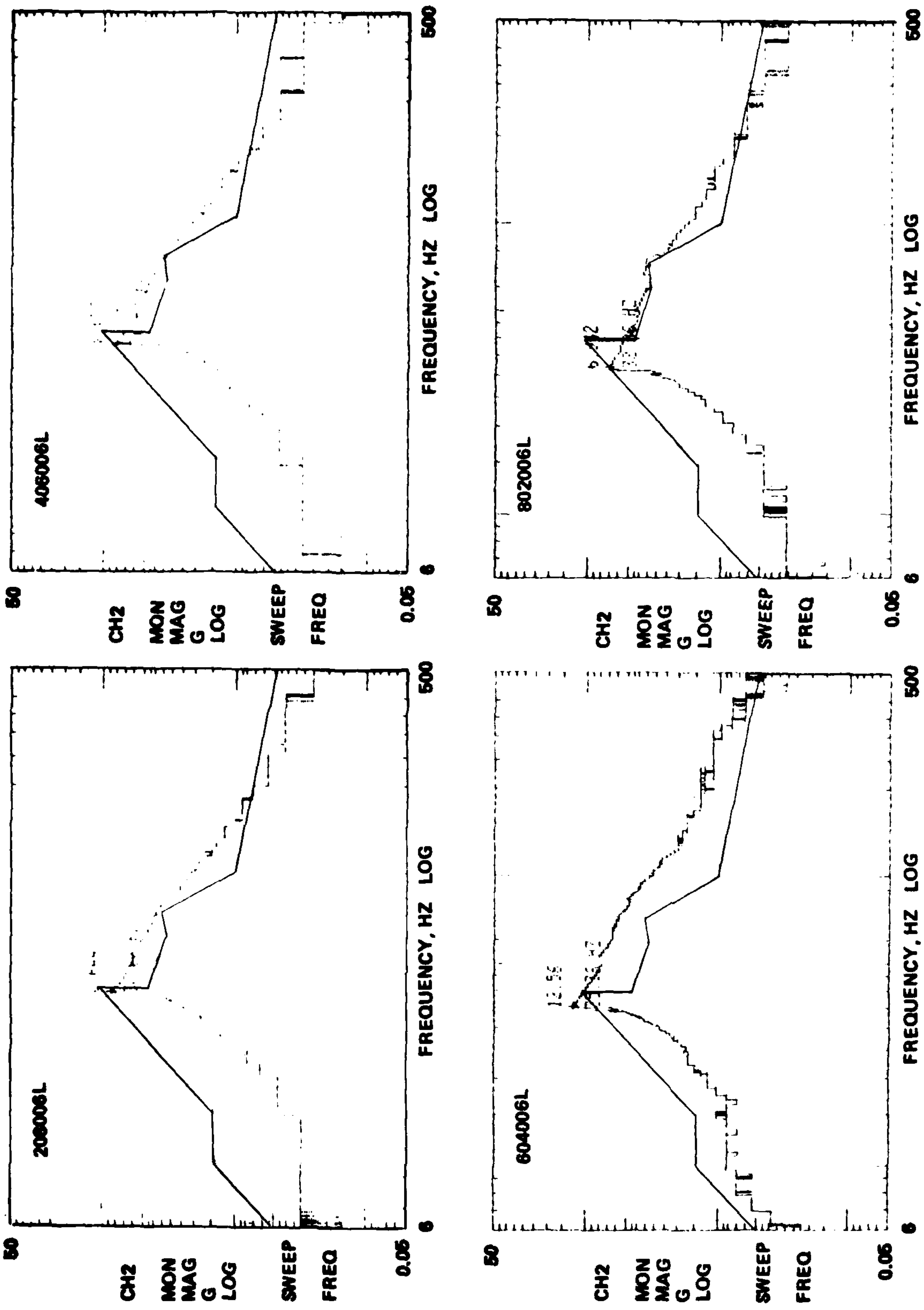

FIGURE 13 VIBRATION OUTPUT FOR NSWC FOAMS 206006L TO 802006L

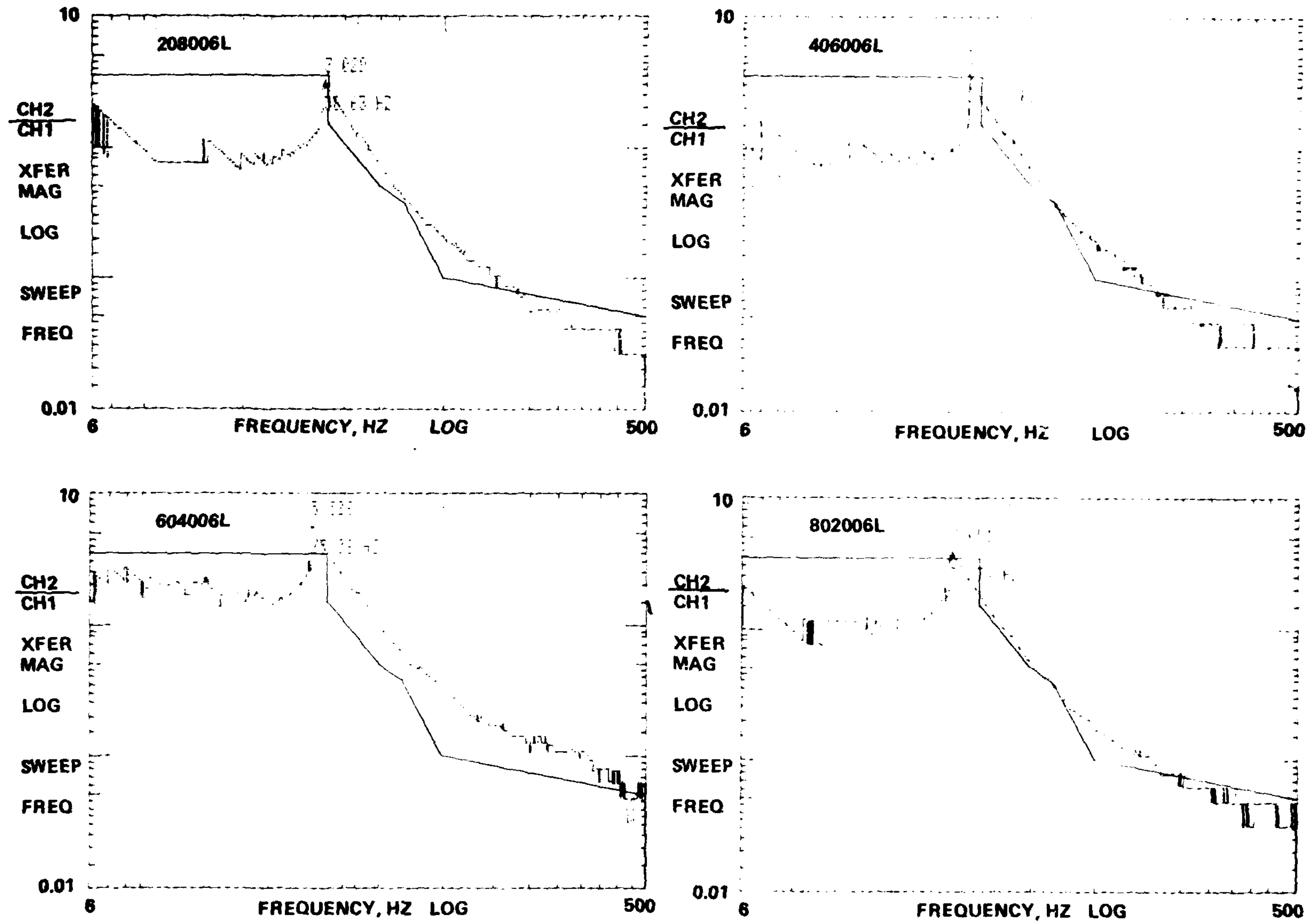

FIGURE 14 VIBRATION TRANSMISSIBILITY FOR NSWC FOAMS 208006L TO 802006L

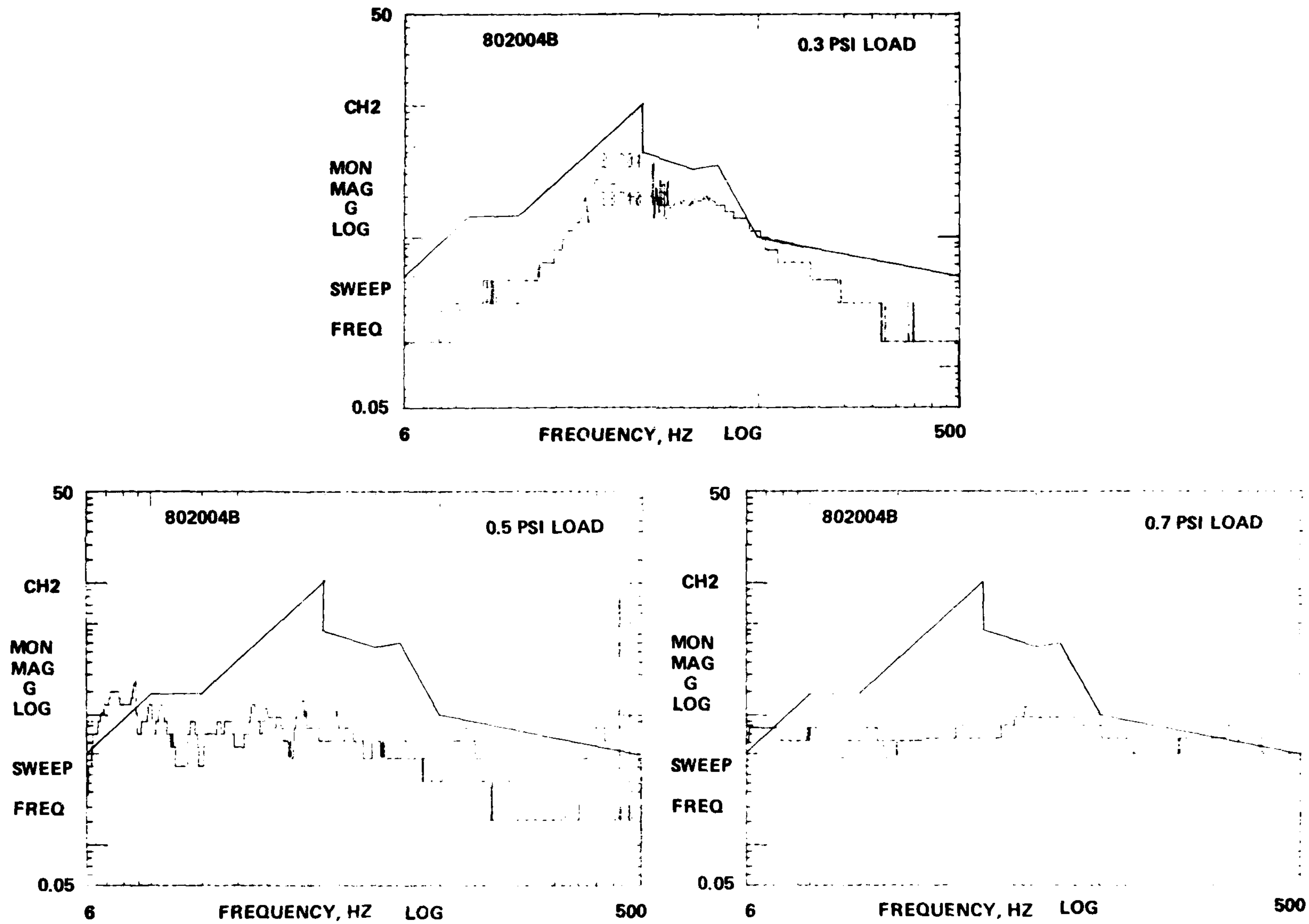

FIGURE 15 VIBRATION OUTPUT FOR NSWC FOAM 802004B UNDER DIFFERENT LOADS

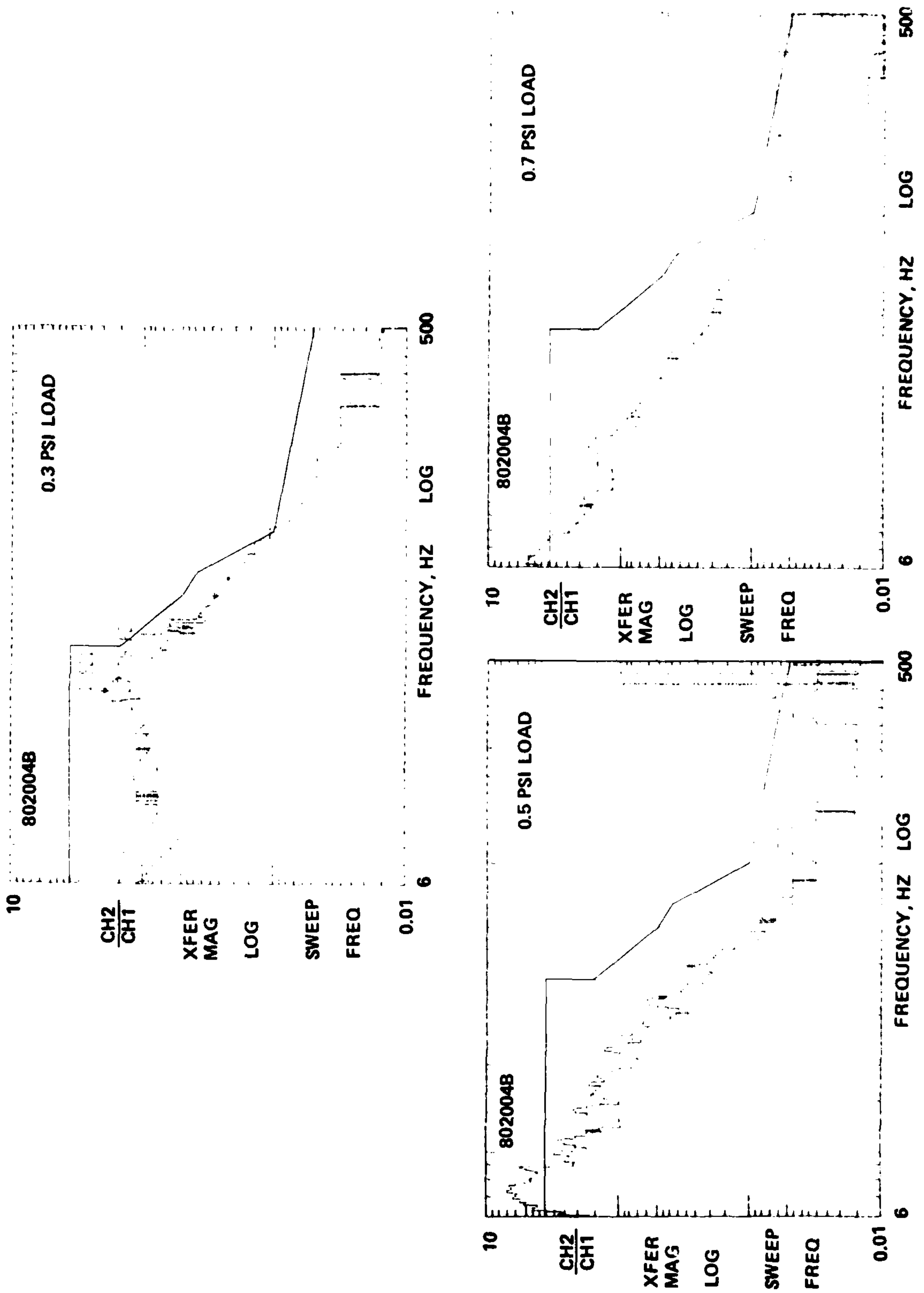

FIGURE 16 VIBRATION TRANSMISSIBILITY FOR NSWC FOAM 802004B UNDER DIFFERENT LOADS

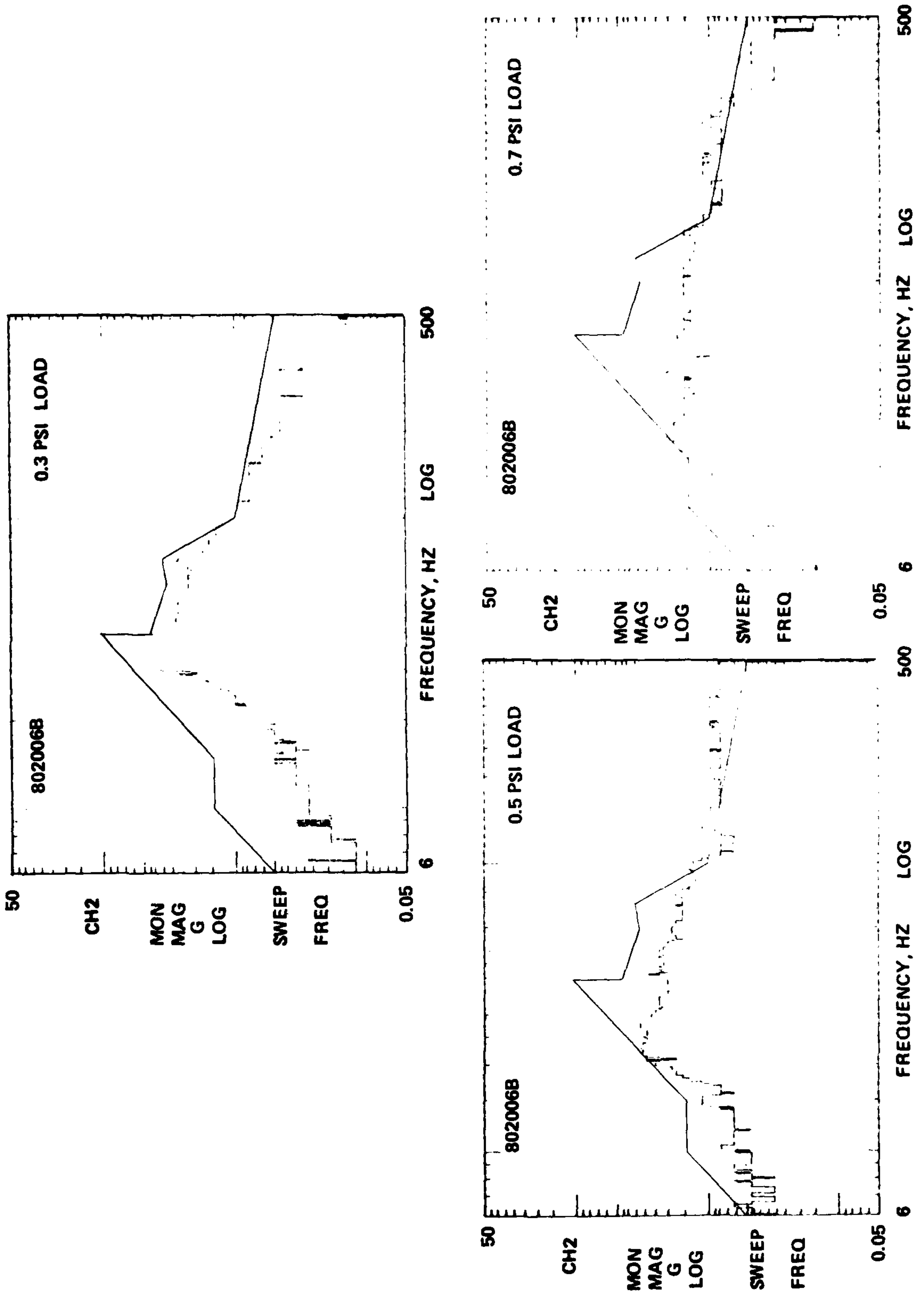

FIGURE 17 VIBRATION OUTPUT FOR NSWC FOAM 802006B UNDER DIFFERENT LOADS

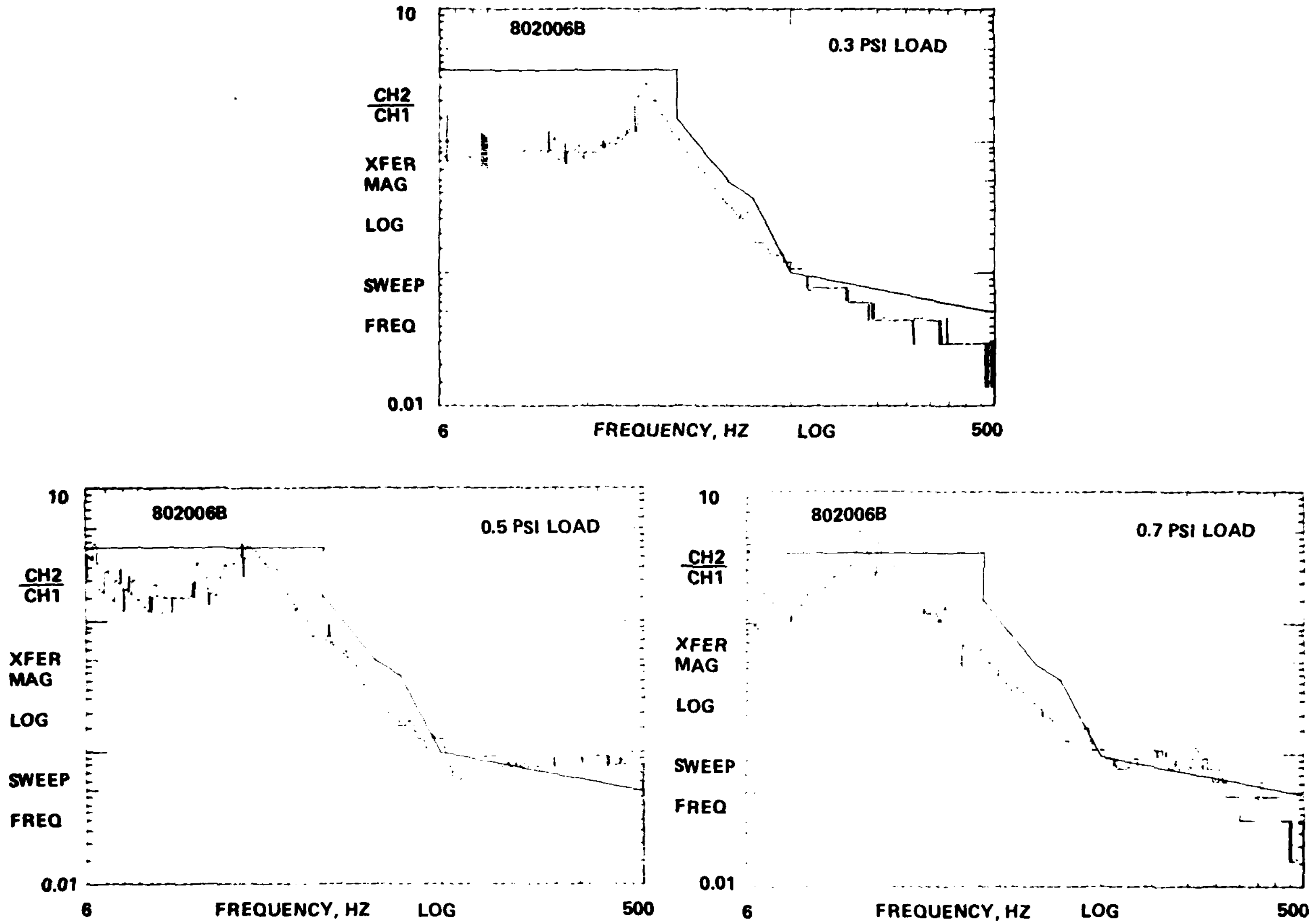

FIGURE 18 VIBRATION TRANSMISSIBILITY FOR NSWC FOAM 802006B UNDER DIFFERENT LOADS

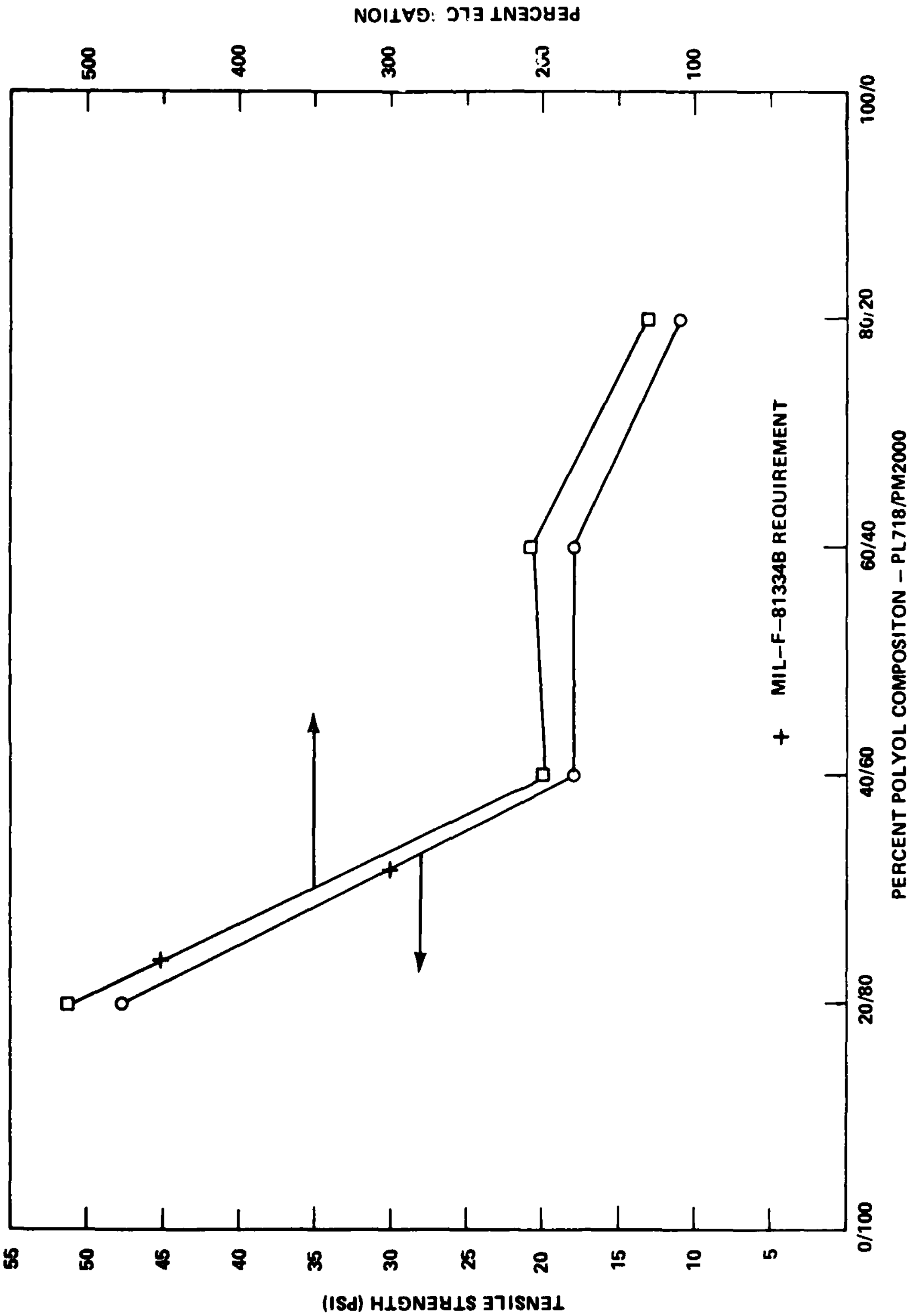

FIGURE 19 FOAM TENSILE STRENGTH/ELONGATION PROPERTIES VS. POLYOL COMPOSITION (4 LBS./CU. FT.)

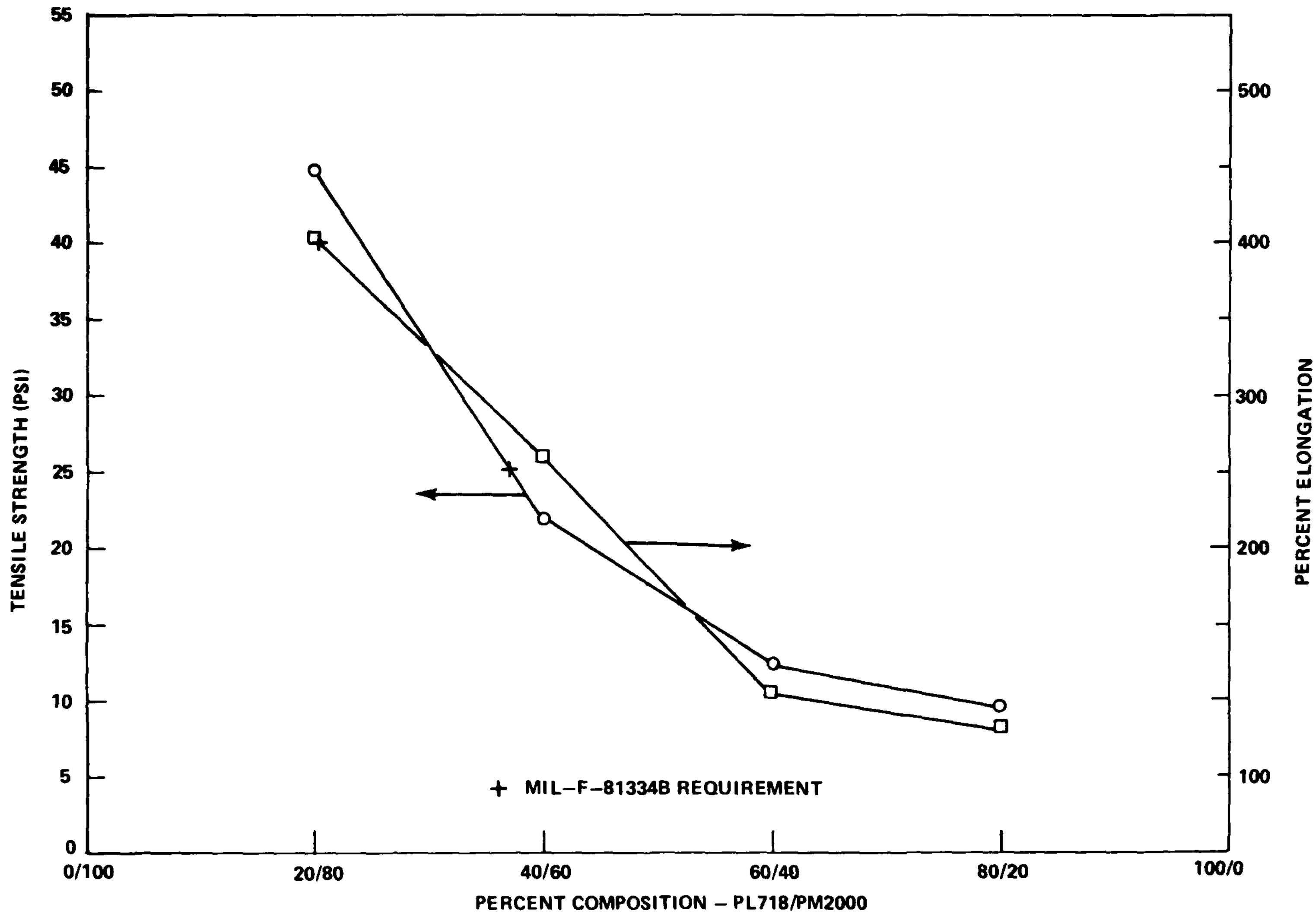

FIGURE 20 FOAM TENSILE STRENGTH/ELONGATION PROPERTIES VS. POLYOL COMPOSITION (6 LBS./CU. FT.)

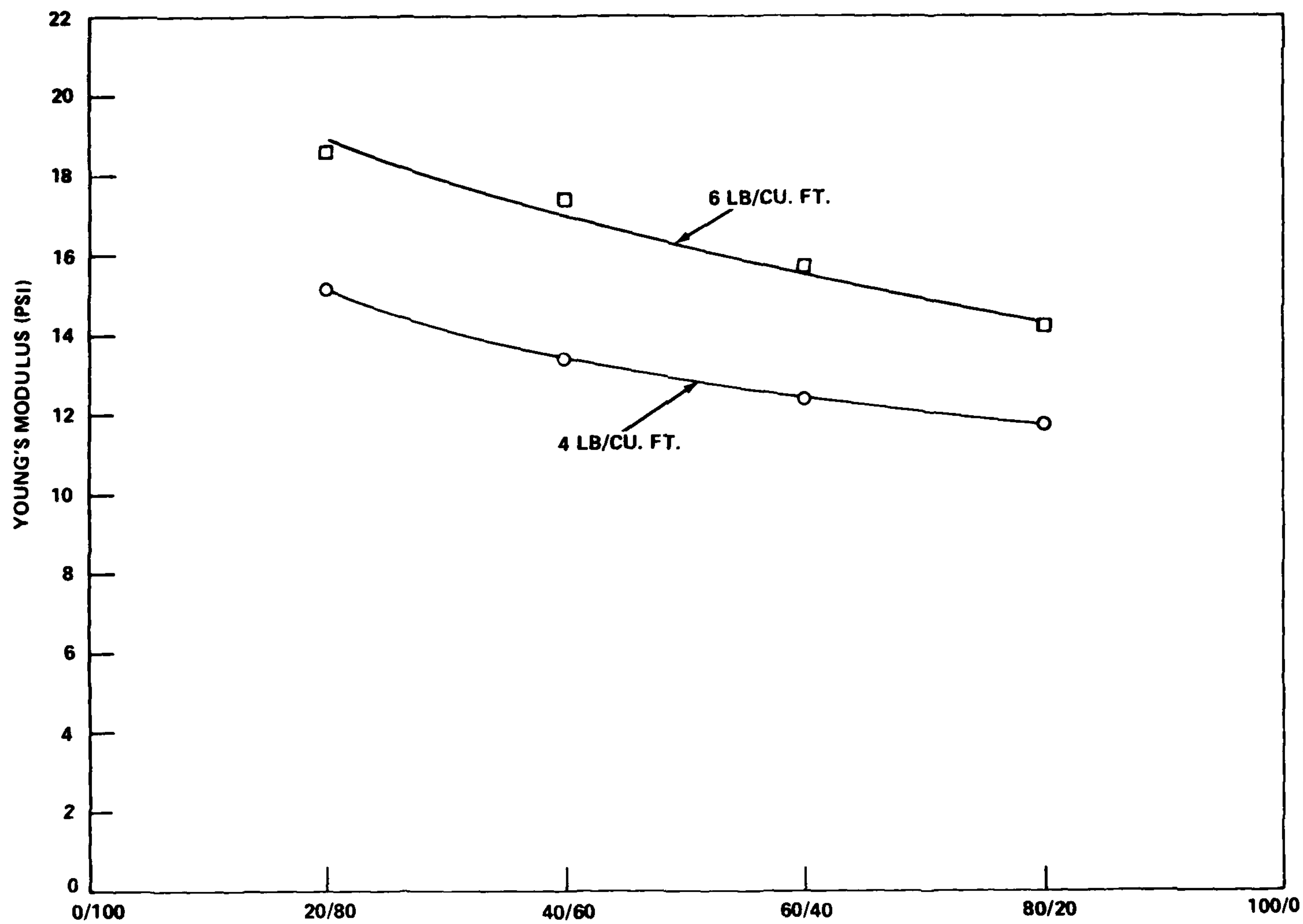

FIGURE 21 YOUNG'S MODULUS VS. POLYOL COMPOSITION FOR NSWC FOAMS AT DIFFERENT DENSITIES

CHEMICAL GLOSSARY

Resins

PL-718 - Pluracol 718 - poly(oxypropylene) triol (BASF Wyandotte Chemical Company)

PM-2000 - Polymeg 2000 - poly(oxytetramethylene) glycol (Quaker Oats Company)

Surfactants

L-520 L-540 L-5740	Silicone surfactant (Union Carbride)
DC-190 DC196	Silicone surfactant (Dow Corning)
B-3136 B-2370	Silicone surfactant (Th. Goldschmidt Products Corporation)

Amine Catalysts

33LV - Dabco 33LV a 33.3% solution of triethylenediamine in dipropylene glycol (Air Products)

NEM - N-ethylmorpholine (Jefferson Chemical)

Tin Catalyst

T-9 - Stannous octoate (M&T Chemicals)

CHEMICAL GLOSSARY (CONT'D)

Isocyanate

TD-80 - Mondur TD 80 (Mobay Chemical Co.)

Colorant

DS-1822 - Black inorganic pigment in an inert liquid medium (Conap Inc.)

APPENDIX A

Foam Formulations

802004B

960 PL-718
240 PM-2000
17.7 H_2O
3.10 33LV
3.24 NEW
12.0 B 3136
6.0 DS-1822
1.44 T-9
294 TD-80
Mix 25 seconds
1600 RPM
Cream 40 seconds

604004B

720 PL-718
480 PM-200
17.7 H_2O
2.88 88LV
12.0 B-3136
6.0 DS-1822
2.40 T-9
294 TD-80
Mix 20 seconds
1600 RPM
Cream 25 seconds

406004B

480 PL-718
720 PM-2000
18.7 H_2O
2.52 33LV
12.0 B-3136
6.0 DS-1822
3.60 T-9
304 TD-80
Mix 15 seconds
1600 RPM
Cream 20 seconds

208004B

240 PL-718
960 PM-2000
18.7 H_2O
2.52 33LV
18.0 B-3136
6.0 DS-1822
6.20 T-9
304 TD-80
Mix 15 seconds
1500 RPM
Cream 20 seconds

802006B

1440 PL-718
360 PM-2000
15.2 H_2O
2.40 33LV
9.60 NEM
9.0 B-3136
9.0 DS-1822
0.90 T-9
327 TD-80
Mix 45 seconds
1700 RPM
Cream 65 seconds

603006B

1080 PL-718
720 PM-2000
16.2 H_2O
2.70 33LV
5.40 NEM
9.0 B-3136
9.0 DS-1822
0.90 T-9
337 TD-80
Mix 25 seconds
1800 RPM
Cream 45 seconds

406006B

720 PL-718
1080 PM-2000
15.2 H_2O
2.70 33LV
5.40 NEM
9.0 B-3136
9.0 DS-1822
1.35 T-9
327 TD-80
Mix 20 seconds
1800 RPM
Cream 30 seconds

208006B

360 PL-718
1440 PM-2000
15.2 H_2O
2.70 33LV
5.40 NEM
9.0 B-3136
9.0 DS-1822
1.8 T-9
327 TD-80
Mix 20 seconds
1700 RPM
Cream 30 seconds

Foam Formulations

802006L	604006L	406006L	208006L
1440 PL-718	1080 PL-718	720 PL-718	360 PL-718
360 PM-2000	720 PM-2000	1080 PM-2000	1440 PM-2000
16.2 H_2O	16.2 H_2O	15.2 H_2O	16.2 H_2O
2.40 33LV	2.70 33LV	2.70 33LV	2.70 33LV
9.60 NEM	5.40 NEM	5.40 NEM	5.40 NEM
9.0 L-540	9.0 L-540	9.0 L-540	9.4 L-540
9.0 DS-1822	9.0 DS-1822	9.0 DS-1822	9.0 DS-1822
0.90 T-9	0.90 T-9	1.35 T-9	1.80 T-9
337 TD-80	336 TD-80	327 TD-80	337 TD-80
Mix 40 seconds	Mix 25 seconds	Mix 20 seconds	Mix 15 seconds
1700 RPM	1650 RPM	1650 RPM	1650 RPM
Cream 60 seconds	Cream 40 seconds	Cream 30 seconds	Cream 25 seconds

802006BF	604006BF	406006BF	208006BF
1440 PL-718	1080 PL-718	720 PL-718	360 PL-718
360 PM-2000	720 PM-2000	1080 PM-2000	1440 PM-2000
16.2 H_2O	16.2 H_2O	15.2 H_2O	16.2 H_2O
2.40 33LV	2.70 33LV	2.70 33LV	3.00 33LV
9.60 NEM	5.40 NEM	5.40 NEM	5.20 NEM
9.0 BF-2370	9.0 BF-2370	9.0 BF-2370	9.0 BF-2370
9.0 DS-1822	9.0 DS-1822	9.0 DS-1822	9.0 DS-1822
0.90 T-9	0.90 T-9	1.35 T-9	1.80 T-9
337 TD-80	337 TD-80	327 TD-80	337 TD-80
Mix 35 seconds	Mix 25 seconds	Mix 20 seconds	Mix 15 seconds
1650 RPM	1650 RPM	1650 RPM	1650 RPM
Cream 50 seconds	Cream 40 seconds	Cream 30 seconds	Cream 25 seconds

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